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HEART RATE MEASUREMENT ALGORITHM IN THE SYSTEM OF REMOTE MONITORING OF HUMAN CONDITION

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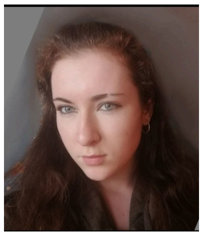

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Abstract. The article discusses the issues of measuring the heart rate during human movement in remote monitoring systems. The algorithm of heart rate measurement based on the processing of spectrograms of cardiograms is described. The implementation of the algorithm makes it possible to obtain a more accurate quantitative assessment of the heart rate in real time in the presence of interference and noise.
Keywords: heart rate, spectrogram, electrocardiogram, real time scale.

Introduction.

The explosive growth of digital medicine is facilitated by new solutions in the field of information technology, artificial intelligence, sensors, robotics, wireless communications, processing and analysis of large amounts of information, augmented and virtual reality. The growth of the industry's demand for IT-solutions is also associated with an increase in the proportion of patients with chronic diseases and necessity to provide them with constant monitoring and long-term care. The coronavirus pandemic has become a powerful stimulus for the development of digital medicine. Information technologies are used in all structural elements of digital medicine: to improve the accuracy of diagnosis and personification of treatment based on medical big data collected within the electronic medical document flow; to analyze medical images obtained by a telemedicine system using computer vision algorithms, etc. One of the promising applications of information technology is the determination of the functional state of a person, the identification of pre-crisis and crisis states through wearable medical electronics systems, including systems for continuous monitoring of the condition of patients. The basic (prototypes) remote monitoring systems, that has currently being developed are focused on real-time monitoring of the following basic physiological parameters: heartbeat, body and environment temperature, tissue oxygen saturation, body position [1,2.3]. It is an important and difficult issue understand how to measure heart rate (HR) via electrocardiograms (ECG) in real time against the background of moderate common–mode interference, mainly induced in power circuits. Wireless body area network (WBAN), which is currently being developed by various foreign companies, as a rule, implement the function of heart rate monitoring[4,5]. In portable real-time devices, the dynamics of a person and his internal organs impose additional complexity on interference in power circuits when measuring heart rate and other vital signs.

Description of the algorithm.

In this paper, to solve the problem, it is proposed to measure heart rate in real time by analyzing the spectrogram of the electrocardiosignal [6,7,8]. This decision is due to the quasi-periodicity of the heartbeat process and the ability to control the behavior of the signal in certain frequency ranges, especially in the ranges least affected by interference in power circuits, as well as the pronounced nature of the QRS-complex of the electrocardiogram, which, as a rule, clearly stands out against the background of noise.

Figure 1 (U is the amplitude of the cardiogram, N is the sample numbers proportional to the current time of the electrocardiographic signal) shows a fragment of the original electrocardiographic signal with QRS-complexes recorded by a portable electrocardiograph from a person in his natural conditions. In this case, the isoelectric line of the electrocardiogram fluctuates along with its elements. This complicates the process of detection and recognition of the QRS-complex. Human movements additionally noticeably distort the signal, in some places almost completely suppressing the QRS-fragment. Sampling period of signal samples td = 2 ms.

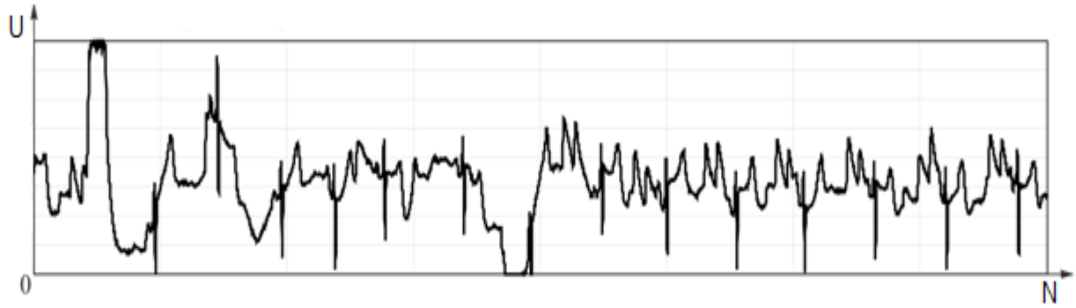

Figure 1. Fragment of the initial electrocardiosignal with QRS-complexes recorded by a portable electrocardiograph

The proposed algorithm for heart rate measurement consists of six stages:

1. ECG registration and calculation of the sliding window fast Fourier transform (FFT) using the Hamming weight function and calculation of the electrocardiogram spectrogram.
2. Formation of the first numerical array, the columns of which are the calculated amplitude spectra of the window Fourier transform, and the lines are frequency slices of the spectrogram on the rage [f1, fk].
3. Calculation of the second Fourier transform of the numeric values of the strings of the first numeric array and the formation of the second numeric array.
4. Search for the coordinates of global highs in the calculated amplitude spectra of the second array.
5. Calculation of heart rate estimates for each amplitude spectrum of the second array, taking into account the weights of the harmonics adjacent to the global highs and the decreasing nature of the fragment of the amplitude spectrum.
6. Averaging of the set of heart rate estimates calculated at the previous stage.

Based on these steps, the heart rate measurement algorithm is based on a two-fold FFT of the initial electrocardiosignal. Heart rate is estimated by repeated FFT of frequency slices of the spectrogram in the range [f1, fk]. A second numerical array is formed, the rows of which are the amplitude spectra obtained as a result of calculating the second Fourier transform. Figure 2 shows one of the amplitude spectra (a sequence of string values of the second numeric array), where L is the harmonic number of the spectrum proportional to the frequency. Our own research has shown that in the heart rhythm of an electrocardiogram, the spectral region from approximately f1 = 12 Hz to fk = 45 Hz is least susceptible to interference. Accordingly, the heart rate measurement in the proposed algorithm is based on peak analysis of the amplitude spectra of the second numerical array, based on the data of frequency slices of the spectrogram with column numbers (or rows, depending on the method of representation of the spectrogram) corresponding to frequencies from the range [f1, fk].

The decreasing nature of the fragment of the amplitude spectrum of the frequency slice means movement from its maximum in both directions to the first rises. Changes in the amplitude of a certain harmonic component of the original signal there is a quasi-periodic, heartbeat-related process that manifests itself in the spectrogram. Its frequency corresponds to the near-peak frequency response region in Figure 2.

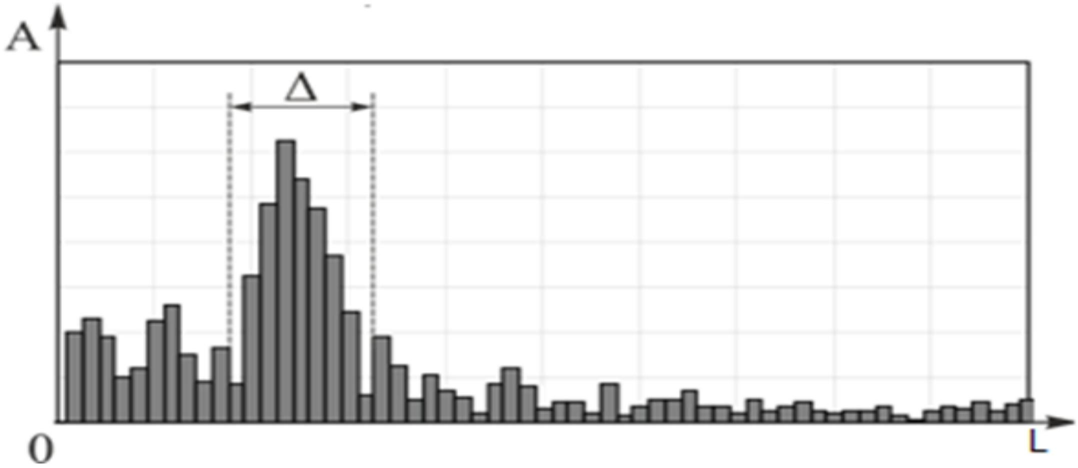

Figure 2. Amplitude spectrum of the frequency slice

To obtain a more accurate estimate of the heart rate, the harmonics adjacent to the maximum A_{jmax} are taken into account in the calculations, taking into account the decreasing nature of the near-maximum fragment of the amplitude spectrum before the first rises. This interval is indicated by the width Δ. The contribution of these harmonics to the heart rate at the Δ-rage is taken into account by means of weighting coefficients wδ proportional to the amplitudes Aδ of harmonics with the numbers δ included in the Δ-rage of the amplitude spectrum of the signal of the frequency slice of the spectrogram, and $\sum \delta\epsilon\Delta \ \omega_\delta$=1:

$$HR_f = \frac{60}{t_d \cdot n} \cdot \sum_{\delta\in\Delta}(w_\delta \cdot \delta),$$

where f ∈[f1, fk] is the index of the frequency slice of the spectrogram of the original electrocardiogram, td is the sampling period of its samples, n is the length of the sliding window. The above formula for HRF is designed to measure heart rate in beats per minute.

Taking into account the weighting contribution of HRF, the final HR value is calculated by averaging HRF over all frequency indices f in the range [f1, fk].

Conclusion.

The proposed algorithm for heart rate measurement is implemented in a portable electrocardiograph based on an ESP32 microcontroller with Tensilica Xtensa LX6 architecture and an RC039 cardiomodule based on an AD8232 amplifier [12]. The average heart rate calculation time is no more than 5 ms for the length of the sliding window n = 128 with a step of its movement equal to the length of the window and the size of the spectrogram matrix (n / 2 × n / 8). To control the heart rate, an analysis of the array of amplitude spectra obtained from the data of frequency slices of the spectrogram is used. The use of time-frequency conversion based on the window Fourier transform for processing this class of signals makes it possible to increase the accuracy of measuring heart rate during human movement.

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АЛГОРИТМ ИЗМЕРЕНИЯ ЧАСТОТЫ СЕРДЕЧНЫХ СОКРАЩЕНИЙ В СИСТЕМЕ ДИСТАНЦИОННОГО МОНИТОРИНГА СОСТОЯНИЯ ЧЕЛОВЕКА

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Аннотация. В статье рассмотрены вопросы измерения частоты сердечных сокращений при движении человека в системах удаленного мониторинга. Описан алгоритм измерения сердечный сокращений, основанный на обработке спектрограмм кардиограмм. Реализация алгоритма позволяет получить более точную количественную оценку частоты сердечных сокращений в реальном масштабе времени в условиях наличия помех и шумов.

Ключевые слова: частота сердечных сокращений, спектрограмма, электрокардиограмма, реальный масштаб времени.